TECHNICAL REPORT

No. 15036-16

on

FURTHER STUDIES OF THE USE OF A VORTEX BURNER TO INVESTIGATE FLAME STABILITY

to

WRIGHT AIR DEVELOPMENT CENTER
WRIGHT-PATTERSON AIR FORCE BASE
OHIO

Contract No. AF 33(038)-12656
E.O. No. 460-35 S.R.-8

BATTELLE MEMORIAL INSTITUTE

February, 1953

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by

Philip F. Kurz

John F. Foster, Supervisor

February, 1953

Technical Report No. 15036-4[1] described a vortex burner for studying the flame stability of a wide variety of fuels and fuel mixtures. The influence of certain burner parameters was described and those which required further investigation were discussed.

This report is a supplement to Technical Report No. 15036-4 and describes the results of further investigations of the burner. Described in this report are the influence of the temperature of the air and of the fuel on the stability of resulting lean flames, the range of useful operation of the burner in a possible practical application, the modification of the burner by the installation of a Smithells[2] tube in order that rich stability limits may be studied, and the pressure drop through the burner

and lines over a wide range of air rates. Still to be studied is the influence on flame stability of burner nozzles with divergent recovery sections longer than three inches.

MODIFICATION OF APPARATUS

The construction and operation of the vortex burner and its auxiliary equipment were described and illustrated in Technical Report No. 15036-4. The burner used in the present experiments was essentially unchanged. A nozzle with a 1/4-in. throat and a 3-in. recovery section was used. A manometer and suitable Bourdon gauges were installed to measure back pressure in the air line at the metering-orifice outlet. These had no influence on the operation of the burner. Other modifications made for a specific purpose, such as the use of a Smithells tube for studying rich and lean blow-off limits, and the use of a refractory surface bearing a thermocouple to study the range of usefulness of the burner, did not change the principle of operation, nor did they affect the behavior of lean flames to an appreciable extent.

In the studies of pressure drop, all four tangential air-admission ports were open. This was done to reduce to a minimum the pressure. It was shown in Technical Report No. 15036-4 that flame stability was independent of the number of air-admission ports which were open.

INFLUENCE OF TEMPERATURE OF AIR AND FUEL ON STABILITY OF PROPANE FLAMES

The influence of the temperature of the air and of the fuel on flame stability was studied at given temperatures in the range of 34 F to 187 F, using propane as the fuel.

Figure 1 shows stability curves at the extremes of the temperature range. The curves for the intermediate temperatures would lie between the two curves shown. They have been omitted in the interests of clarity.

Figure 2 shows the influence of bath temperature on the fuel requirements at blow-off at five air rates. At an air rate of about 21 liters per minute, increasing the mixture temperature from 34 F to 187 F reduces the fuel requirement at the stability limit from 569 to 516 cc per min, or 9.4 per cent. At the top air rate of about 48 liters per minute, the same change in temperature permits the use of only 8.3 per cent less fuel.

Figure 3 shows the influence of bath temperature on the fuel requirements at the stability limit, the linear velocity in the throat, and the back pressure in the air line at an air rate of about 48 liters. The volumetric fuel flows are shown both as metered at 70 F and at the varying throat temperatures between 34 F and 187 F. The average velocity in the throat is shown for air flow alone and for the combined air and fuel flows. The pressure drop is that measured in the air line between the burner and the air-metering-orifice outlet.

From these results, it is believed desirable to investigate the influence of the temperature of the burner on flame stability over a much wider range of temperature. This will require a heated burner nozzle because it is not desirable to preheat the fuel above 200 F. Envisioned for this work is a burner nozzle with a longer recovery section which has a thin wall. The recovery section could then project above the water bath and be heated or cooled externally, as desired, independently of the water

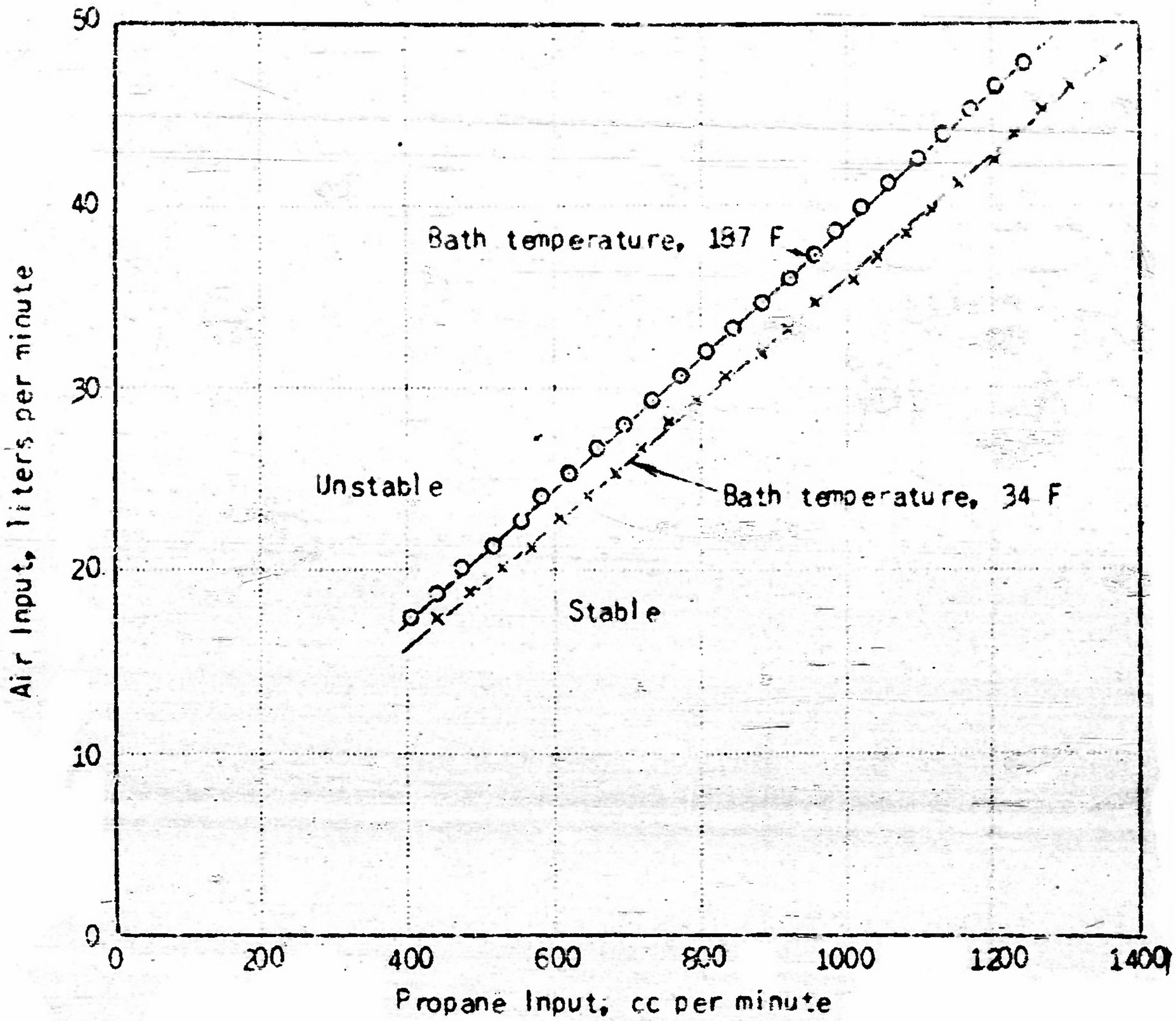

FIGURE 1. STABILITY LIMITS OF PROPANE FLAMES ON A VORTEX BURNER AT TWO BATH TEMPERATURES. AIR AND FUEL METERED AT 70 F.

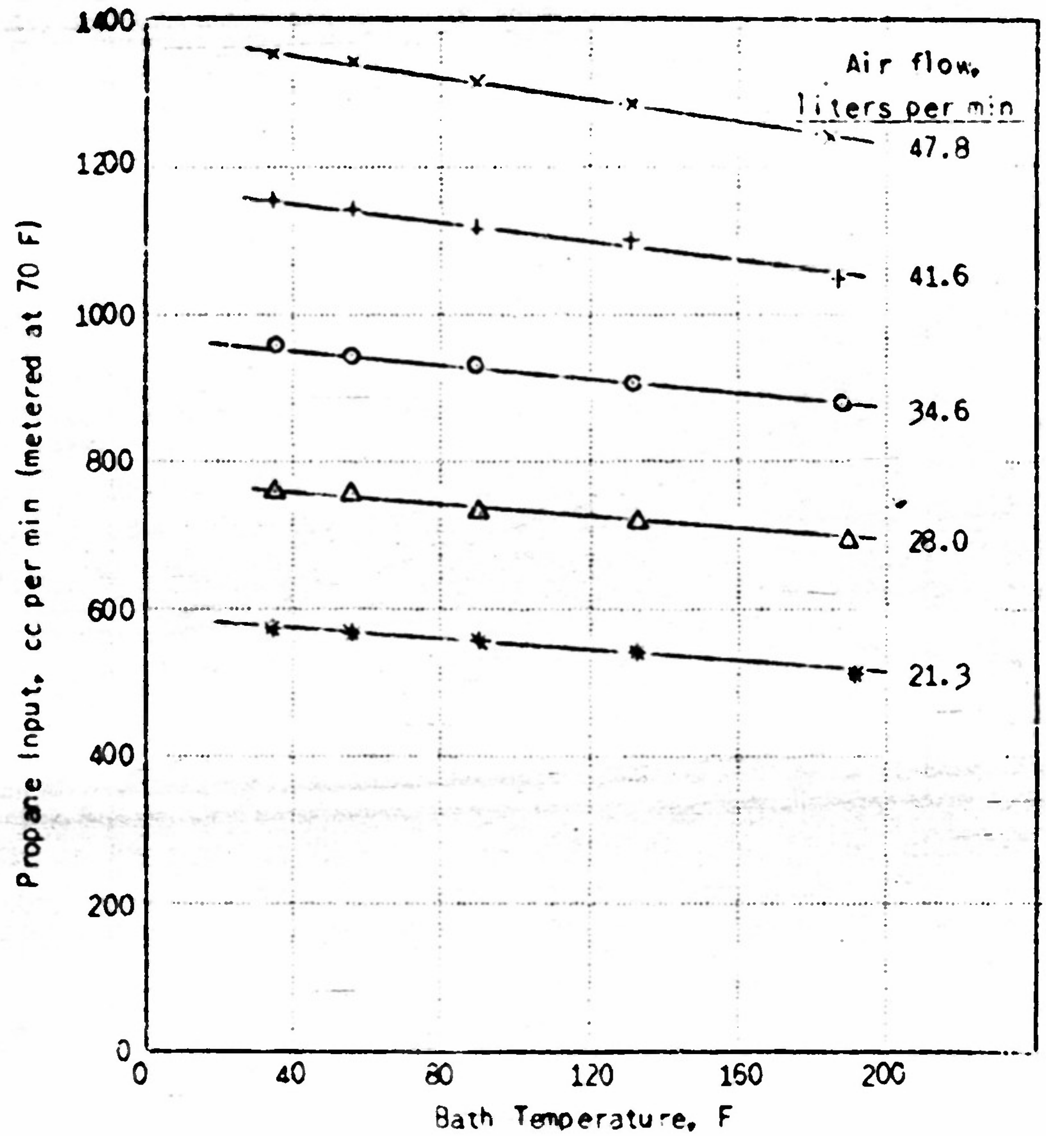

FIGURE 2. INFLUENCE OF TEMPERATURE OF AIR AND FUEL ON FUEL REQUIREMENTS AT BLOW-OFF AT FIVE AIR RATES ON A VORTEX BURNER

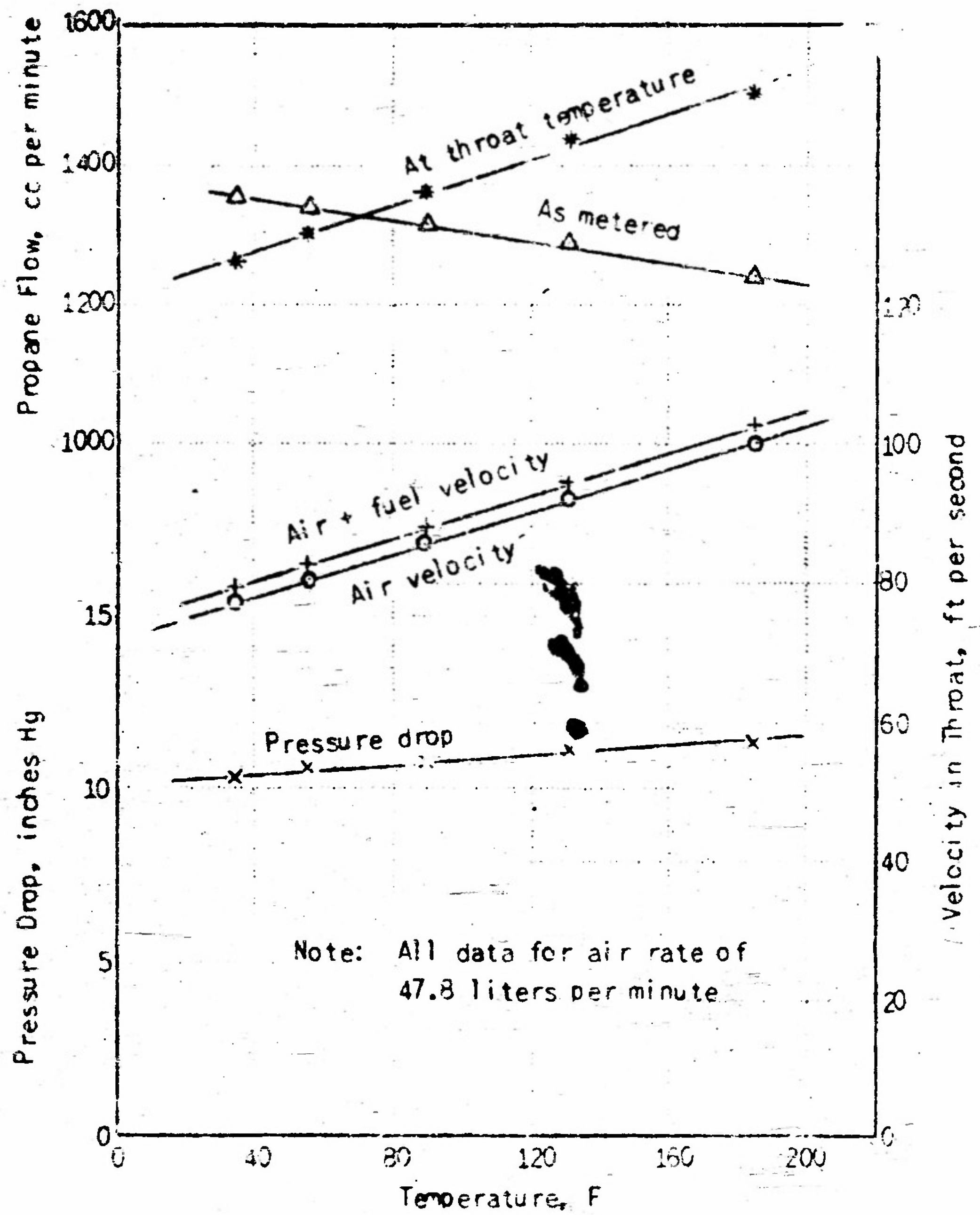

FIGURE 3. INFLUENCE OF TEMPERATURE OF AIR AND FUEL ON FUEL REQUIREMENTS, VELOCITY AND BACK PRESSURE AT ONE AIR RATE ON A VORTEX BURNER

bath, which would serve to keep the fuel cooled below the cracking point until it was mixed with the air in the throat and passed into the combustion sone in the recovery section.

USEFUL OPERATING RANGE OF THE VORTEX BURNER

With the possibility of practical applications of this new burner in mind, the limits of fuel-air mixtures within which efficient combustion occurs were studied by temperature measurements in the flame. A silica insulating brick was pierced in the center of its 4-1/2 in. by 9-in. face and a Chromel-Alumel thermocouple was placed in the hole so that the metallic junction just protruded from the surface of the brick. The brick was placed above the port of the vortex burner so that the thermocouple was approximately on the axis of the burner and about two in. above the burner port. The arrangement is shown schematically in Figure 4.

In the experimental work, a flame was ignited on the vortex burner with the thermocouple-bearing brick in place. The fuel flow was then reduced until the flame was barely stable. This flame was maintained until periodic readings on the potentiometer showed that temperature equilibrium had been reached. Then the flow of fuel was increased by convenient increments, until the temperature of the thermocouple dropped off sharply and the flame became large and of a configuration which would be useless in releasing heat rapidly in a small volume.

Figure 5 shows the change in the temperature of the thermocouple with change in the composition of methane-air mixtures at air rates of 14.3 and 47.7 liters per minute on the vortex burner. If the empirically

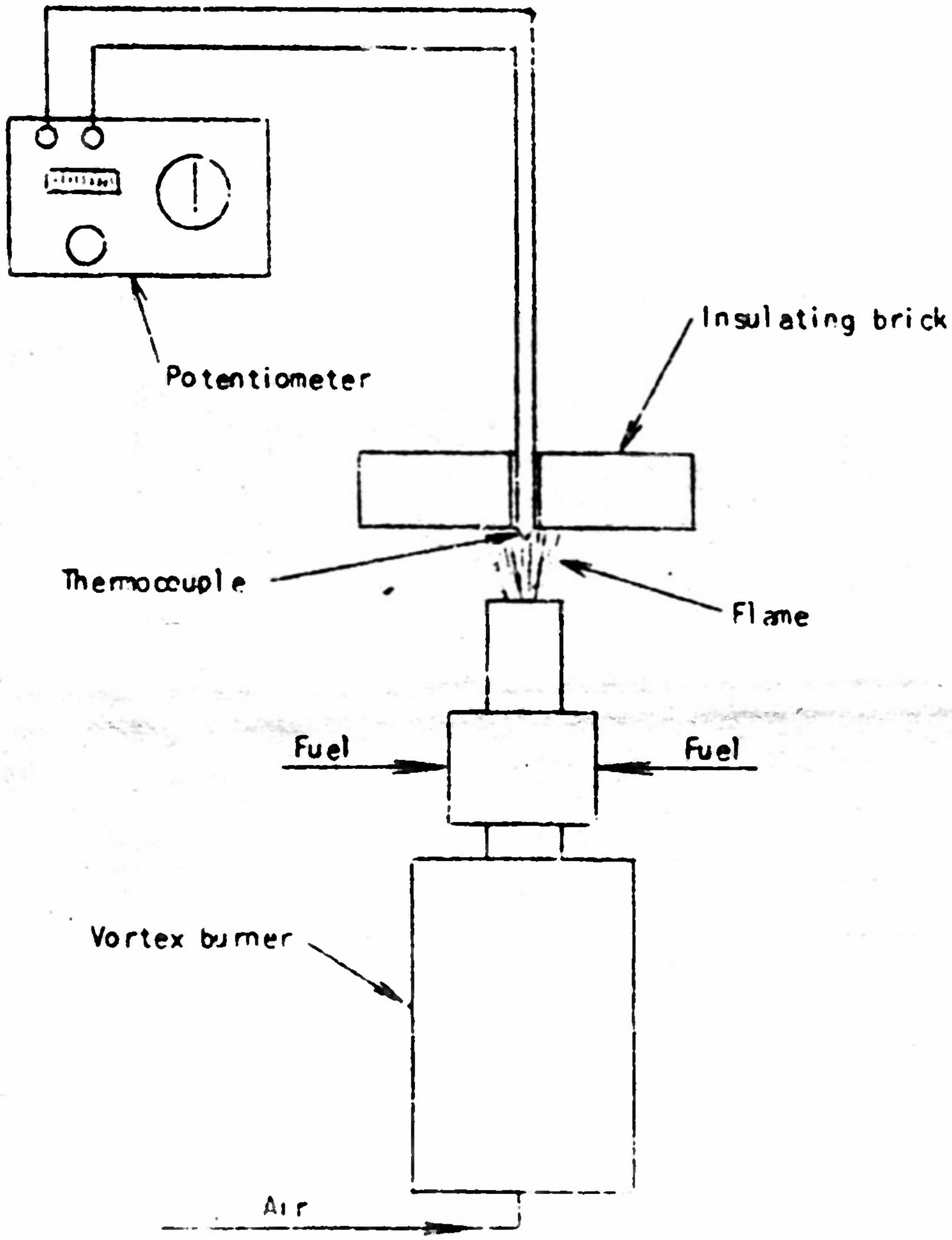

FIGURE 4. ARRANGEMENT OF THERMOCOUPLE FOR STUDYING RANGE OF USEFULNESS OF VORTEX BURNER

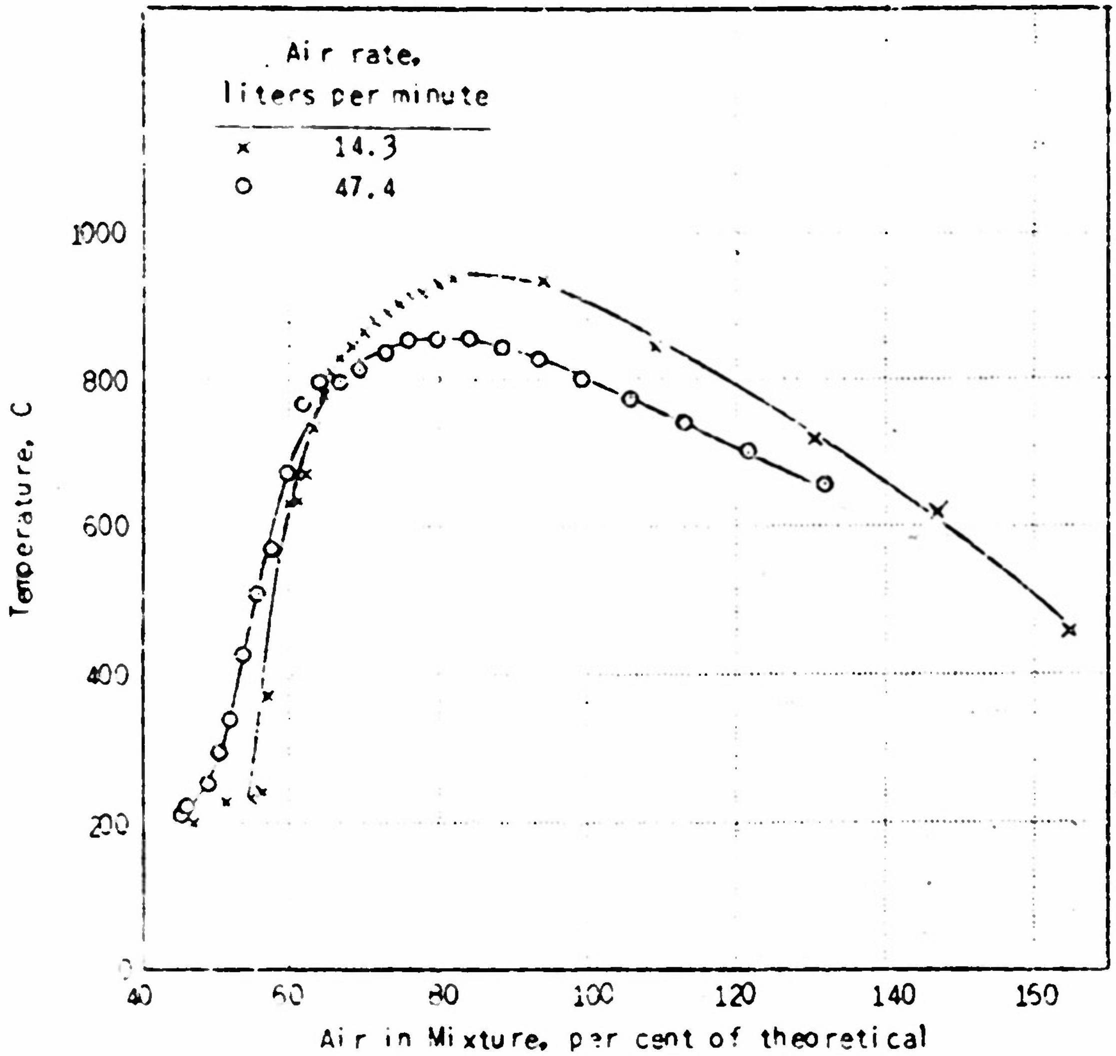

FIGURE 5. CHANGE IN THERMOCOUPLE TEMPERATURE OVER A RANGE OF FUEL-AIR COMPOSITION FOR METHANE FLAMES AT AIR RATES OF 14.3 AND 47.7 LITERS PER MINUTE ON A VORTEX BURNER

obtained temperature level of 650 C is arbitrarily taken as the limit of satisfactory usefulness, then the burner is useful with mixtures containing from 60 to 130 per cent of theoretical air at high air rates, and from 60 to 140 per cent of theoretical air at low air rates.

This empirical method of testing appears to be satisfactory for evaluating the limits of usefulness of the vortex burner.

USE OF THE VORTEX BURNER FOR STUDYING RICH STABILITY LIMITS

To study rich stability limits with the vortex burner, a Smithells flame-separator tube is installed to exclude ambient air from the environs of the burner port. No other modifications to the burner proper are required.

Figure 6 shows schematically the arrangement of the burner and the Smithells tube. The bottom of the Smithells tube extends below the level of the water in the constant-temperature bath surrounding the burner. A spray of water was directed against the outer periphery of the Smithells tube to maintain the tube approximately at a uniform temperature that consistent data might be obtained.

With this arrangement, lean blow-off was studied by the procedure outlined in the Technical Report No. 15036-4. To determine the point of rich blow-off at a given air rate, the flow of fuel was increased by convenient increments until the vortex flame lifted from the burner port, rose up the Smithells tube and burned in a large Bunsen-type flame on the rim of the Smithells tube. If the flow of fuel was then decreased by one increment the flame flashed down the Smithells tube and burned stably in

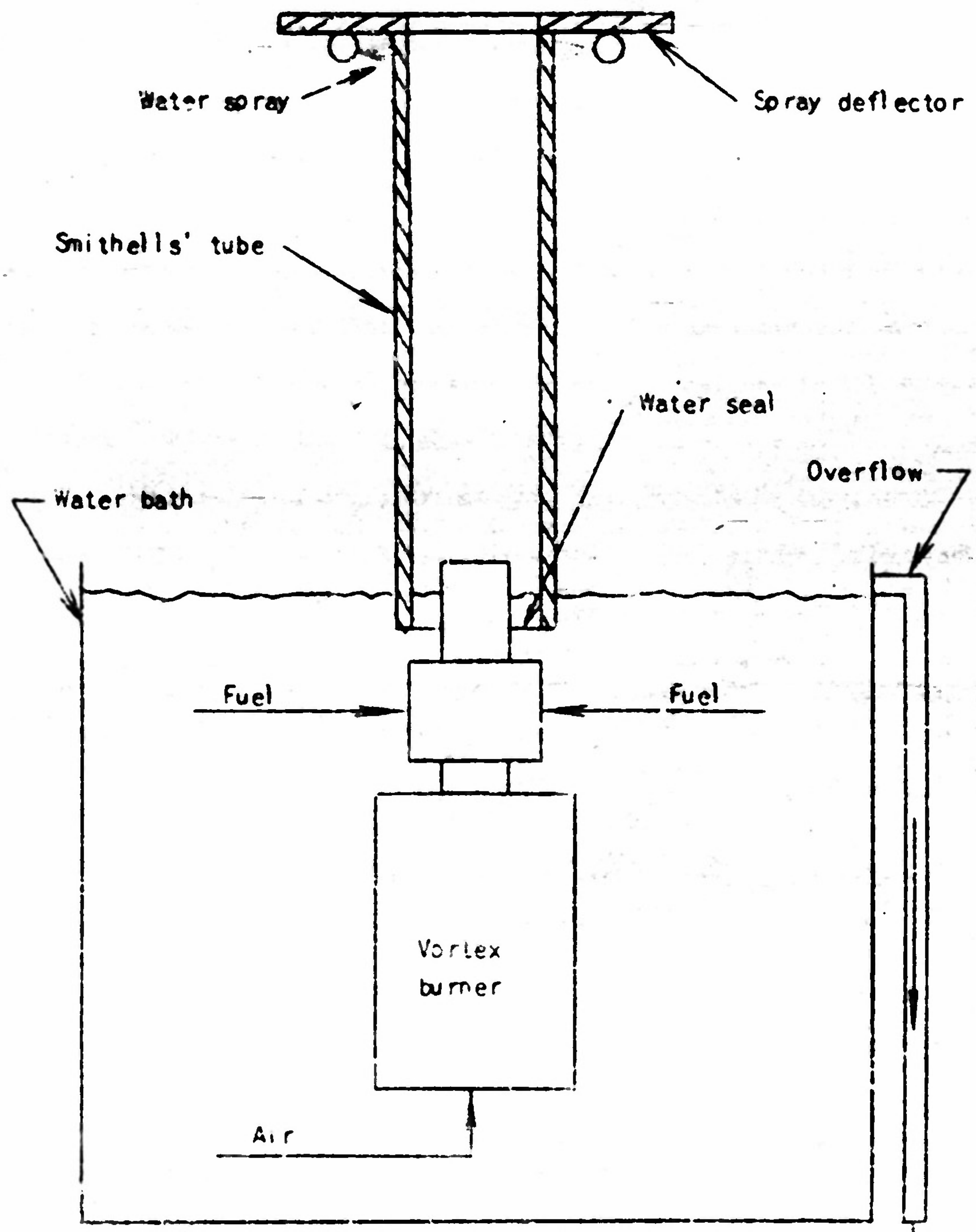

FIGURE 6. SCHEMATIC DRAWING OF VORTEX BURNER WITH AN EXTERNALLY COOLED SMITHELLS' TUBE FOR STUDYING STABILITY OF LEAN AND RICH FLAMES

the recovery section of the vortex burner. This point is quite sharply defined and represents a reproducible measure of rich blow-off.

Figure 7 shows lean blow-off curves for methane flames on the vortex burner with and without a Smithell tube. Also shown is the rich blow-off curve obtained when the Smithells tube is used. The double reversal in the curvature of the lean blow-off curve obtained with the Smithells tube is believed to be caused by some variations in the degree of external cooling of the Smithells tube by the water spray.

The results of these experiments indicate that a further investigation of both lean and rich blow-off using a more refined, water-jacketed Smithells tube and a variety of fuels should give useful information.

PRESSURE DROP THROUGH BURNER AND DELIVERY LINES

The pressure drop through the burner and the air delivery lines is important because it is convenient to operate metering orifices within the range of critical flow. Thus, the ratio of driving pressure to back pressure at the orifice must be about two or greater. Careful measurements of pressure drops in the system have shown that the major portion of the total pressure drop occurs in the 1/8-in. pipe lines making up the system that delivers fuel and air from the orifices to the burner. The earlier use of 1/4-in. lines permitted periodic oscillations in the system at low flow rates that interfered with stability studies by extinguishing the flames prematurely.

The solution, therefore, was to reduce the size of the lines and to use a single orifice or combination of two or three sizes to give critical flow at the desired flow rates.

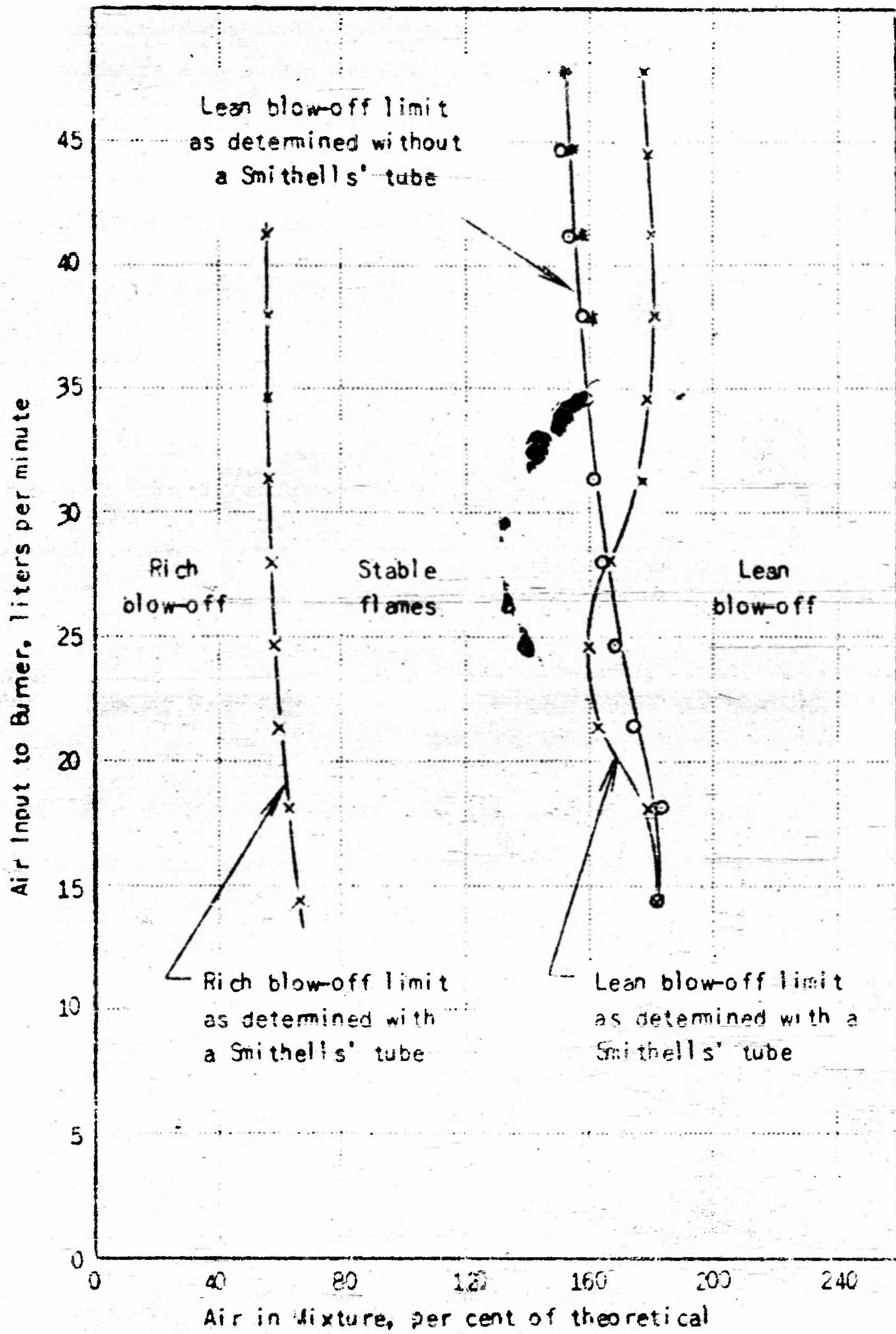

FIGURE 7. LEAN BLOW-OFF WITH AND WITHOUT A SMITHELLS' TUBE AND RICH BLOW-OFF WITH A SMITHELLS' TUBE FOR METHANE FLAMES OVER A RANGE OF AIR RATES ON A VORTEX BURNER

Figure 8 shows the results of calibration studies of the rates of flow obtainable with three different single orifices and their combustions operating in the range of critical flow. It is evident that, with driving pressures of 20 to 60 psig, flow rates of 11 to 141 liters per minute can be attained in the present system, which is satisfactory.

BEHAVIOR OF FLAMES AT BLOW-OFF AT HIGH AIR RATES ON THE VORTEX BURNER

Preliminary work has shown that the vortex burner can be used to study the blow-off of flames at high air rates.

Figure 9 shows the air-fuel composition of the methane flames at blow-off over a range of linear air velocities in the burner throat. Air velocities up to 160 feet per second in the throat can be used, with tolerable pressure drops in the burner itself.

Figure 10 shows the pressure drop and velocity in the throat for methane-air mixtures at air rates up to 93 liters per minute on the vortex burner.

CONCLUSIONS AND COMMENTS

As a result of this investigation of the characteristics of the vortex burner for studying hydrocarbon flames, the following conclusions may be drawn:

1. Flame stability is dependent on the temperature of the air and of the fuel admitted to the burner. An increase in the temperature of the unburned reactants produces an increase in flame stability, that is, at a given air rate less fuel is required when the reactants are at a higher temperature than when they are at a low temperature.

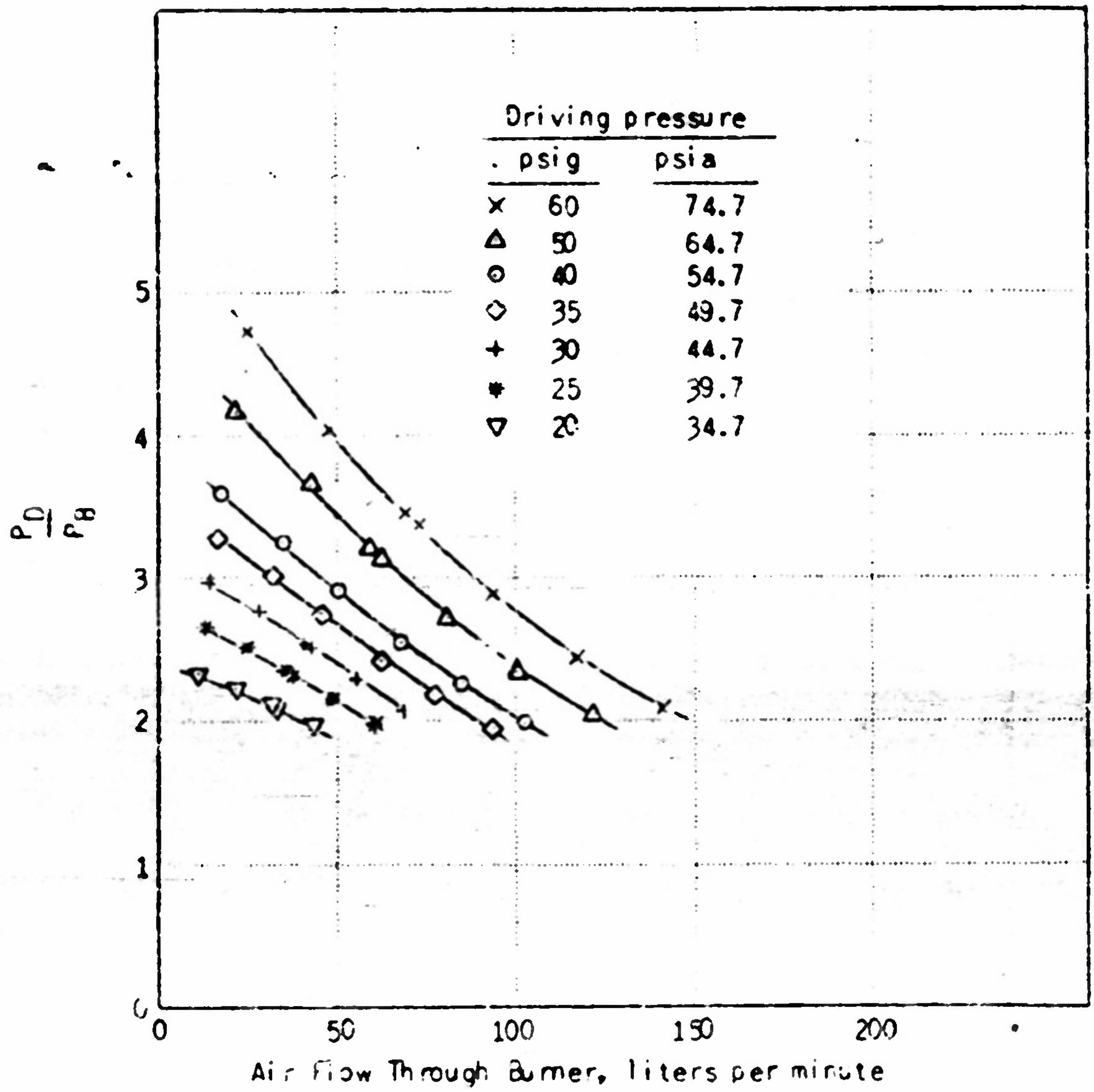

FIGURE 8. RELATIONSHIP BETWEEN AIR FLOW THROUGH BURNER AND THE RATIO OF DRIVING PRESSURE TO BACK PRESSURE AT SEVEN LEVELS OF DRIVING PRESSURE ON A VORTEX BURNER

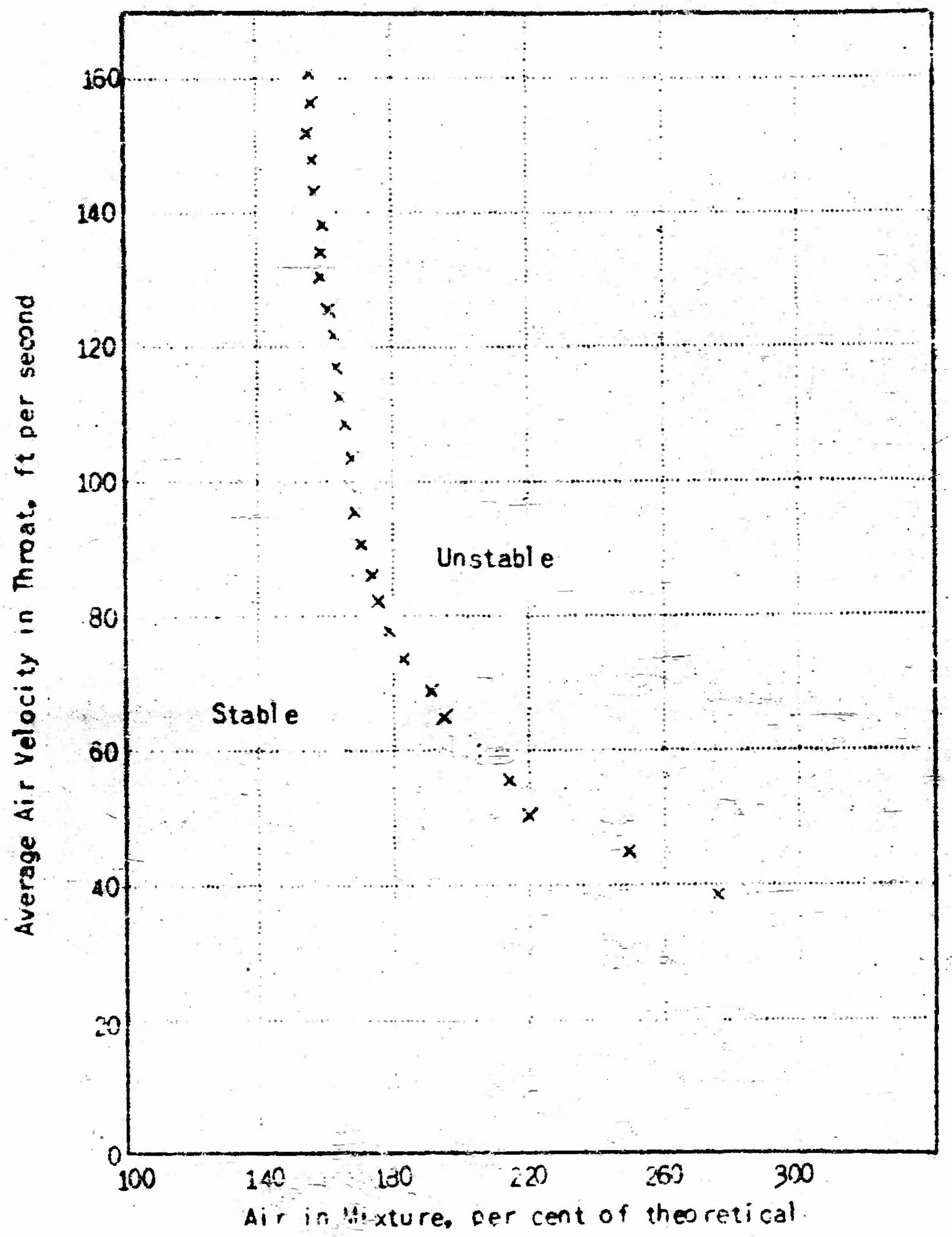

FIGURE 9. AIR VELOCITY AT BLOW-OFF FOR METHANE-AIR FLAMES OVER A RANGE OF MIXTURE COMPOSITION ON A VORTEX BURNER WITH A 1/4-INCH THROAT AND A 3-INCH RECOVERY SECTION

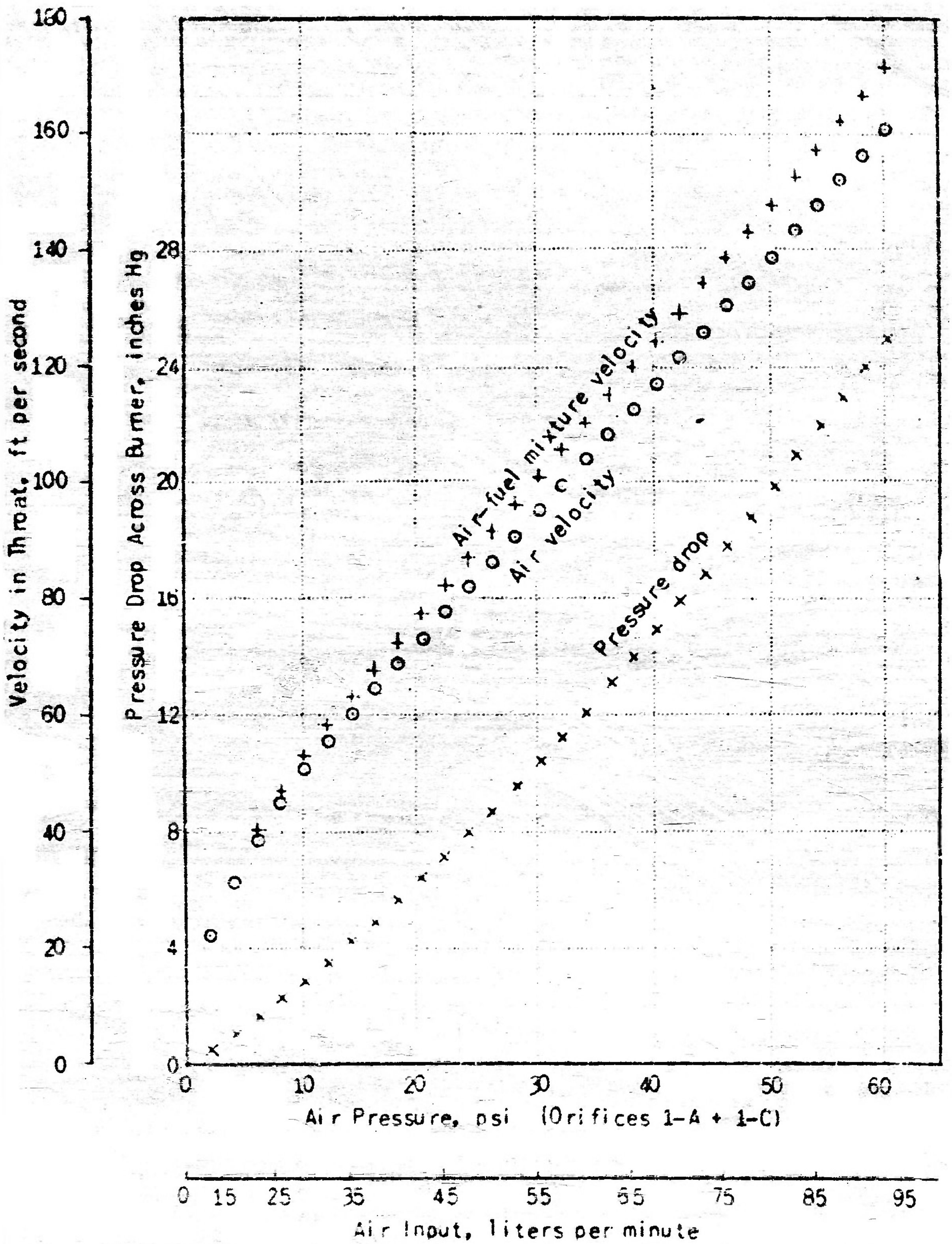

FIGURE 10. PRESSURE DROP AND VELOCITY IN THROAT FOR METHANE-AIR MIXTURES AT VARIOUS AIR RATES ON A VORTEX BURNER WITH A 1/4-INCH THROAT AND A 3-INCH RECOVERY SECTION

2. The practical operating range of the burner with methane-air flames appears to include mixtures containing 60 to 140 per cent of theoretical air. This factor requires further study with other fuels and fuel mixtures.

3. The vortex burner fitted with a Smithells tube should prove useful in studying the behavior of mixed fuels at rich blow-off.

4. The rather high pressure drop encountered in the system appears to result from the length of the supply lines and the presence of numerous fittings. Larger lines would reduce pressure drop, but they were unsuitable at low flow rates because of oscillations induced in the system.

5. The vortex burner, in its present form, appears to function satisfactorily in blow-off studies with lean flames at air rates up to 93 liters per minute, air equivalent to velocities of up to 160 fps in the throat.

The work suggests that it would be of interest to study the effect of externally heated recovery sections on the nature of hydrocarbon flames. Further studies should be made of blow-off at very high air rates and also of the possibility of using larger air lines to permit higher rates of air flow.

REFERENCES

1. Kurz, P. F., "The Vortex Burner - A Useful Tool for Studying the Flame Stability of Gaseous Fuels and Fuel Mixtures", Battelle Technical Report No. 15036-4 to Wright Air Development Center, Contract AF 33(038)-12656, May, 1952, 12 pages.

2. Smithells, A., and Ingle, H., "The Structure and Chemistry of Flames", Trans. Chem. Soc., London, Vol. 61, 1892, pp. 204-226.

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